United States Patent Application for:

REDUCING DEPOSITION OF PROCESS RESIDUES ON A SURFACE IN A CHAMBER

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REDUCING DEPOSITION OF PROCESS RESIDUES ON A SURFACE IN A CHAMBER

CROSS-REFERENCE

This application is a continuation-in-part of U.S. Patent Application Serial No. 09/096,728 entitled "CHAMBER HAVING IMPROVED PROCESS MONITORING WINDOW," filed on June 11, 1998, which is incorporated herein by reference in its entirety.

BACKGROUND

The present invention relates to an apparatus and method for reducing the deposition of process residues on a surface in a chamber.

In substrate fabrication processes, semiconductor, dielectric, and conductor materials are formed on a substrate and etched to form patterns of gates, vias, contact holes or interconnect lines. These materials are typically formed by chemical vapor deposition (CVD), physical vapor deposition (PVD), oxidation and nitridation processes. For example, in CVD processes, a reactive gas is used to deposit a layer of material on the substrate, and in PVD processes, a target is sputtered to deposit material on the substrate. In oxidation and nitridation processes, a layer of oxide or nitride, typically silicon dioxide or silicon nitride, respectively, is formed by exposing the substrate to a suitable gaseous environment. In etching processes, a patterned etch-resistant mask of photoresist or hard mask is formed on the substrate by photolithographic methods, and the exposed portions of the substrate are etched by an energized gas. In such processes, it is often desirable to change process conditions or stop processing of the substrate at a predetermined stage. For example, in the etching of gate structures, it is desirable to stop etching of overlying polysilicon when the underlying gate oxide is reached. As another example, it is often desirable to stop a deposition, oxidation or nitridation process when a predetermined thickness of material is obtained.

During the substrate fabrication processes, it is desirable to reduce the deposition of process residues on the walls and other surfaces in the chamber. The process residues can flake off and contaminate the substrate. The residues may also interfere with the passage of radiation through the wall, for example, when a widow is

provided on the wall and the residues deposited on the window attenuate the intensity of the radiation passing through the window. The radiation may be monitored by conventional process monitoring methods to determine completion of a process stage or reaching of an endpoint of a process. For example, such methods may include, without limitation, (1) plasma emission analysis in which an emission spectra of a plasma in a chamber is analyzed to determine a process endpoint, as disclosed in U.S. Patent Nos. 4,328,068 and 5,362,256; (2) ellipsometry, in which a polarized light beam reflected from the substrate is analyzed to determine a phase shift and magnitude of the reflected beam, as disclosed in U.S. Patent Nos. 3,874,797 and 3,824,017; and (3) interferometry, in which radiation reflected off the substrate is monitored as disclosed in U.S. Patent No. 4,618,262; all of which are incorporated herein by reference in their entireties.

Thus, it is also desirable to reduce the deposition of process residue on the chamber surfaces, especially the surface of a wall or window in the chamber.

SUMMARY

The present invention provides an apparatus and method capable of satisfying these needs. In one aspect, the present invention comprises a substrate processing apparatus comprising a process chamber comprising a substrate support, gas inlet, gas energizer, gas exhaust, and a wall having a recess that is sized to reduce the deposition of process residues therein.

In another aspect, the present invention comprises a substrate processing apparatus comprising a chamber having a support, gas inlet, gas energizer, and exhaust, and a wall, and means for reducing the formation of process residue on the wall, whereby a substrate held on the support may be processed by process gas introduced by the gas inlet, energized by the gas energizer, and exhausted by the exhaust.

In another aspect, the present invention comprises a method of processing a substrate in a chamber, the method comprising placing the substrate in the chamber, providing an energized gas in the chamber to process the substrate, and providing a recess in a wall of the chamber, the recess being adapted to reduce the formation of process residue therein.

In another aspect, a substrate processing apparatus comprising a process chamber comprising a substrate support, gas inlet, gas energizer, gas exhaust, and a wall comprising an internal surface, and a recess originating at the internal surface of the wall, the recess having an aspect ratio sized to reduce the deposition of process residues therein.

In a further aspect, a substrate processing apparatus comprising a process chamber comprising a substrate support, gas inlet, gas energizer, gas exhaust, and a wall having a recess that is sized to reduce the deposition of process residues therein; a magnetic field source adapted to maintain a magnetic field near the portion of the wall having the recess; and a process monitoring system capable of monitoring a process that may be conducted on a substrate in the process chamber through the recess in the wall.

In yet another aspect, a substrate processing apparatus comprising a process chamber comprising a substrate support, gas inlet, gas energizer, gas exhaust, and a wall having a recess that is sized to reduce the deposition of process residues therein; an electrical field source adapted to maintain an electrical field about the recess; and a process monitoring system capable of monitoring a process that may be conducted on in the process chamber through the recess in the wall.

In yet another aspect, a substrate processing apparatus comprising a process chamber comprising a substrate support, a gas inlet, a gas energizer, a gas exhaust, and a sidewall about the support, the sidewall having at least one recess sized to reduce the deposition of process residues therein.

In yet another aspect, the present invention comprises a method of processing a substrate in a chamber, the method comprising placing the substrate in the chamber, providing an energized gas in the chamber to process the substrate, providing a recess in a sidewall of the chamber, and passing radiation through the recess.

DRAWINGS

While the description, drawings, and appended claims below illustrate exemplary features of the invention, it is to be understood that each of the features can be used in the invention in general, not merely in the context of the particular drawings, and the invention includes any combination of these features.

Figures 1a, 1b and 1c are schematic sectional views of exemplary embodiments of a chamber according to the present invention;

Figures 2a and 2b are schematic sectional views of chamber walls having a recessed portion;

Figure 3 is a schematic sectional view of a separable masking portion comprising a recess and covering a window in a chamber wall;

Figure 4 is a schematic sectional view of another embodiment of a masking portion having a recess over a window and showing a process monitoring system;

Figure 5a is a schematic sectional view of a wall comprising a recessed masking portion and a window portion;

Figure 5b is a schematic top view of the wall of Figure 5a;

Figures 6a to 6c are schematic sectional views of exemplary embodiments of walls comprising masking portions having multiple recesses;

Figure 7a is a schematic sectional view of another embodiment of a wall having a masking portion with an array of recesses with one or more diameters;

Figure 7b is a schematic top view of the wall of Figure 7a;

Figure 8a is a schematic sectional view of another embodiment of a wall having a masking portion with an array of hexagonal recesses;

Figure 8b is a schematic top view of the wall of Figure 8a;

Figure 9a is a schematic sectional partial view of a chamber having an electromagnetic field source to maintain a magnetic field about across a window in the chamber;

Figure 9b is a schematic top view of an electromagnetic field source comprising a magnet having facing magnetic poles;

Figure 9c is a schematic top view of another electromagnetic field source comprising a plurality of magnets;

Figure 10a is a schematic sectional partial view of a chamber comprising an electromagnetic field source to maintain an electrical field across a window in the chamber;

Figures 10b to 10d are schematic top views of different embodiments of electrodes that may be used maintain an electrical field across a window;

Figures 10e and 10f are schematic partial sectional views of chambers having different electrode embodiments;

Figure 11a is a graph showing a transmission spectrum of radiation reflected from a substrate that passes through (a) a clean window, and (b) a window exposed to a process plasma for 52 hours;

Figure 11b is a graph showing the decreasing amplitude of substrate reflected radiation over time due to an increasing thickness of process residues formed on a window of a chamber over several days of chamber operation;

Figure 12 is a graph showing a determined thickness of process residues formed on a window in relation to the aspect ratio of a recess in a masking portion covering the window;

Figure 13a is a graph showing the peak-valley amplitude of radiation reflected from the substrate and the PMT gain % after about 100 hours operation of an etching chamber;

Figure 13b is a graph showing the % transmission of radiation through a window as a function of the wavelength of radiation before and after 100 hours of etching in the chamber;

Figures 14a and 14b show the relative amplitude of substrate reflected radiation passing through the window before etching and after 100 hours of etching in the chamber, respectively; and

Figure 15 shows a deposition rates of process residues formed on a window with a masking portion (denoted by M) and on a window without a masking portion, for different process gas recipes.

DESCRIPTION

A substrate processing apparatus **20** is used to fabricate active or passive electronic devices on a substrate **30**. In an exemplary embodiment, the apparatus **20** comprises a process chamber **35** having walls **38** that define a process zone **40** for processing the substrate **30**, as for example, illustrated by Figure 1a. The chamber walls **38** may be made from a metal or ceramic material or both. For example, the walls **38** may include a sidewall portion made from a metal, for example, aluminum; and a ceiling portion made from a ceramic, such as for example, one or more of Al_2O_3, SiO_2, AlN, BN, Si, SiC, Si_3N_4, TiO_2, ZrO_2 and mixtures and compounds thereof, for example, quartz. The process zone **40** contains a substrate support **45** for supporting a substrate **30**, and which may include an electrostatic chuck **50** to electrostatically hold the substrate **30**. Process gas is introduced into the process zone **40** through a gas supply **65** that includes a gas source **70**, one or more flow control valves **75**, and one or more gas inlets **80**. Spent process gas and etchant byproducts are exhausted from the process chamber **35** via an exhaust system **85** which includes exhaust pumps **90**, and a throttle valve **95** is provided to control the pressure of process gas in the process chamber **35**.

A gas energizer **60** couples electromagnetic energy to the process gas to form energized and neutral gaseous species. The chamber embodiment of Figure 1b represents a DPS-type chamber **35** from Applied Materials, Santa Clara, California. In this process chamber **35**, the gas energizer **60** comprises an antenna **100** maintained adjacent to the ceiling **55** of the process chamber **35** to energize the process gas in the process zone **40** by inductively coupling energy to the process gas. At least a portion of the ceiling **55** is made from a material that is permeable to electromagnetic energy, such as a dielectric material, for example, aluminum oxide. Alternatively, or in combination, the process gas may be energized by capacitively coupling energy to the process gas by charging process electrodes such as the support **45** and sidewalls **96** around the substrate **30**. In another chamber design (not shown), such as the IPS-type chamber also from Applied Materials, the ceiling **55** comprises a semiconducting material that serves as a process electrode for capacitively coupling RF energy into the process chamber **35**. The frequency of the energy coupled to the process gas is typically from about 50 KHz to about 60 MHz. For example, an RF voltage at these frequencies may be applied to the inductor antenna **100** by an antenna power supply **104** at a (source) power level of from about 500 to about 2000 Watts to energize the process gas.

In yet another chamber design (not shown), a magnetic field may also be applied to the energized process gas by electron cyclotron resonance or by a magnetic field generator such as a magnet or electromagnetic coil, as for example, in the MxP-type chamber also from Applied Materials, and generally described in commonly assigned U.S. Patent No. 4,842,683, issued June 35, 1989, which is incorporated herein by reference in its entirety. The process gas may also be energized in a remote chamber (not shown) which is typically adjacent to the process chamber **35**, as for example, in the MxP/RPS-type chamber, also from Applied Materials. The remote chamber is generally upstream from the process chamber **35** and that may comprise a gas energizer that couples electromagnetic energy to activate the process gas in the remote chamber. A suitable electromagnetic source (also not shown), comprises for example, a microwave applicator, a microwave tuning assembly, and a magnetron microwave generator.

A process monitoring system **25** may be used to monitor a process being performed in the process chamber **35** by for example, plasma emission analysis, ellipsometry, or interferometry. Typically, the process monitoring system **25** monitors the process through a radiation permeable portion of the wall **38**. For example, the wall

38 may include a window portion **130** that allows certain types of radiation to pass therethrough. For example, the window **130** may be substantially permeable to ultraviolet, visible or infrared radiation that may be generated in the plasma or reflected from the substrate **30** or from a surface in the chamber **35**. For example, when a process monitoring system **25** is provided to direct a radiation beam **148a** from a radiation source **150** onto the substrate **30**, and monitor the substrate reflected beam **148b**, as illustrated in Figure 2a, the window **130** is permeable to the radiation that is emitted by the radiation source **150** and reflected by the substrate **30**. Thus, the window **130** may be made from a material substantially permeable to the radiation wavelengths or frequencies that are monitored by the process monitoring system **25**. For infrared, visible, and UV radiation permeability, the window **130** may be made of a ceramic, such as for example, one or more of Al_2O_3, Si, SiO_2, TiO_2, ZrO_2 or mixtures and compounds thereof. The ceramic may also comprise a monocrystalline material such as sapphire (monocrystalline alumina) that may exhibit erosion resistance in a halogen containing plasma, such as a fluorine containing plasma. Suitable sapphire windows may be obtained from Kyocera Ceramics, San Diego, California. Generally, the window **130** may comprise a polygonal, rectangular or circular shape. The surfaces of the window **130** may be polished smooth to reduce scattering of radiation passing through the window **130**. For example, scattering of visible, ultraviolet and infra-red radiation is reduced when the window **130** has a surface roughness of less than about 1 μm.

In the embodiment illustrated in Figure 1a, the window **130** is an integral portion of the wall **38** of the chamber **35**. The window **130** is positioned in the ceiling **55** directly above the substrate **30** and is shaped and sized to allow a radiation beam transmitted therethrough to be incident on the substrate **30** at an almost vertical incidence angle, i.e., at from about 85 to about 95 degrees, which may be used to observe a depth change of a trench being etched on the substrate **30**. The window **130** may also be located at other portions of the wall **38**, such as on a sidewall or at a different portion of the ceiling **55**, such as for example, when the radiation evaluated is a emission spectra from a plasma in the chamber **35**.

In one version of the present invention, the wall **38** comprises a recess **145** that originates at an internal surface **142** of the wall **38**. The recess **145** may extend to or terminate at a window **130** in the wall **38**, as illustrated in Figures 5a and 5b, or the

recess may terminate at other structures or devices of the chamber **35**. The recess **145** may be an aperture, trench or groove that extends through a portion or the entire thickness of the wall **38**. The recess **145** may comprise a cross-sectional shape that is circular, polygonal, triangular, hexagonal, square or rectangular. For example, the recess **145** may comprise a passageway that allows radiation to pass between the process chamber **35** and the process monitoring system **25** while controlling access of energized gas species to the window **130** to reduce the formation of process residues on the window **130**. In this version, the recess **145** is shaped and sized to allow a sufficient amount of radiation to pass therethrough to operate the process monitoring system **25** while still controlling the access of the energized gas species therein. For example, the recess **145** may be shaped and sized to pass both a line of sight incident radiation beam **148a** and a line of sight reflected radiation beam **148b** from a substrate **30**, and for interferometric or ellipsometric analysis. The recess **145** may also be shaped and sized to monitor a spectral emission from the plasma, for example to perform a plasma emission analysis.

The aspect ratio of the recess **145** (ratio of depth to opening size) controls the access of ion and neutral gas species into the recess **145**. For example, the depth of the recess **145** may be sized to control the distance that must be traveled by the gas species before they reach, for example, the window **130** in the recess **145**. The opening size of the recess **145** may be sized to control the quantity of the gas species that enter into the recess **145**. The recess **145** may also be sized to exclude the chamber plasma from entering the recess **145** by, for example, forcing sufficient sidewall recombination to extinguish the plasma before it reaches the window **130**, the recess size depending upon the plasma sheath thickness. For example, fewer gas species pass across the depth of the recess **145** when the gas species collide with the recess sidewalls or otherwise combine with one another while passing through the passageway of the recess **145**. It may be desirable to reduce the number of gas species that enter or travel through the recess **145** and/or it may also be desirable to allow some of the gas species to travel through the passageway to sputter or etch away the process residue deposits that form on the recess sidewalls **148** or window **130**.

Thus, it is believed that the aspect ratio of the recess **145**, which is the ratio of its depth to its opening size, may be sized to restrict entry of certain gas species (such as for example, neutral gas species that may form the process residues) while allowing

other gas species (such as for example, charged or chemically active species that may assist in removing the process residues) to enter and travel through the recess **145**, thereby controlling the type or quantity of the gas species that reach the window **130**. In one embodiment, useful in the plasma etching of polysilicon, the recess **145** comprises an aspect ratio of at least about 0.25:1, and optionally, less than about 12:1. The aspect ratio may also be at least about 3:1 and less than about 7.5:1, for example, from about 4:1 to about 5:1. A recess **145** having such aspect ratios resulted in little or no deposition of process residue on its sidewalls **148** and very little deposition on the window **130** in the recess **145.** However, smaller aspect ratios are useful in certain processes to selective filter out and prevent undesirable gas species from reaching the window **130**, for example, aspect ratios of from about 0.25:1 to about 3:1, or from about 0.5:1 to about 2:1.

Generally, it is believed that the presence of a recess **145** in front of the window **130** reduces the deposition of process residues on the window **130** by reducing the access of gaseous species that form process residues, (for example, neutral gaseous species which may be the residue forming species) or by allowing access of residue removing species (for example, highly energized gaseous ions that may etch away the process residues). Thus, the operation of the recess **145** may occur in different modes, depending on the aspect ratio, depth or opening size, of the recess **145**, and the properties of the process being conducted in the chamber. For example, in a silicon etching process conducted at a gas pressure of from about 2 to about 10 mTorr, it is believed that two different mechanisms may be demonstrated. In a first mode, it is believed that the flux of residue forming gas species reaching the window **130** is reduced by means of multiple sidewall collisions and subsequent sticking of the gas species with the recess sidewalls **148**. The recess **145** may also operate by excluding (if present) the plasma from entering the recess **145** by forcing sufficient sidewall recombination to extinguish the plasma before it reaches the window **130**. A suitable recess **145** comprises an aspect ratio of at least 4:1 and a diameter of less than 10 times the plasma sheath thickness (if plasma is present). Increasing the aspect ratio may further reduce the already reduced process residue deposition rate on the window **130**. In the process example, a recess **145** with an aspect ratio of about 5:1 with a hole diameter of about 4 mm would reduce the process residue deposition rate to less than 1% of that without the recess **145**.

It is further believed that a second mode of operation of the recess **145** may occur when the size and aspect ratio of the recess **145** changes the balance of etching to

deposition to produce a net removal of the process residues formed on the window **130**. The second mode is useful when there are energized gas species present (such as from a plasma but a plasma is not required) which will etch away the process residues formed on the window **130**. The specific size and aspect ratio of the recess **145** depends on the process. For example, a single recess **145** with an aspect ratio of 1.5 may be sufficient to produce a net etching of process residues on an inside window **130**. For such an aspect ratio, an array of recesses **145** may also be used to provide a large line of sight area of the substrate **30**. To maximize the transmission of line of sight radiation reflected from the substrate **30** or a chamber wall, the array of recesses **145** may be non-circular holes, such as hexagons in a hexagonal close-packed array, or squares in a square array, and with reduced wall thickness between the recesses **145**, as for example, shown in Figure 8b.

The depth or opening size of the recess **145** may be selected independently of one another or in relation to a preselected aspect ratio. For example, an optimized depth *d* may also depend upon the gas flow rate, gas pressure or even gas composition, because it is related to the length of the mean free path of the gas species, their molecular sizes, and their reactivity. For example, for a silicon etching process conducted at a gas pressure of about 1 to about 1000 mTorr, an optimized recess depth *d* may be from about 0.5 to about 500 mm or even from about 10 to about 50 mm. The opening size of the recess **145** may have a linear dimension, such as a width for rectangular or parallelogram recesses, or may have a circular dimension, such as a diameter for round holes. The opening size of the recess **145** is typically from about 0.1 to about 50 mm.

The passageway through the recess **145** may be positioned vertically relative to a processing surface of the substrate **30**, as shown for example in Figure 6a, or at an inclined angle relative to an internal surface of the chamber **35**, as shown for example in Figures 6b and 6c. The passageway angle relative to the primary direction of travel of energized gas species also controls the access of the energized gas species into the recess **145** and to the optional window **130**. For example, the recess **145** may be angled so that its longitudinal or central axis is along the direction of travel of the energized species. The recess **145** may also be oriented at an inclined angle relative to the plane perpendicular to the substrate **30**, as in Figures 6b and 6c, for example, at an angle of less than about 90 degrees or for example from about 60 to about 90 degrees, or from about 70 to about 88 degrees, and in one embodiment about 80 degrees. The inclined angled recess **145** may also be used to selectively pass through line of sight radiation that is

reflected from the substrate **30** or radiation that originates from a particular region of the plasma.

In another version, a plurality of recesses **145** may be arranged to pass radiation reflected from one or more different regions of the substrate **30** or portions of the plasma in the chamber **35**. For example, one recess **145** may be inclined at an angle of 70 degrees, another at an angle of 80 degrees, and yet another at an angle of 90 degrees. This would allow monitoring of a line of sight (to the substrate or to a portion of the plasma) through one or more of the recesses **145**, providing desired flexibility in selection of the appropriate process monitoring region.

In another version, one or more windows **130** may be provided in a sidewall **96** of the chamber **35**. In the version illustrated in Figure 1c, for example, two windows **130** are provided in sidewalls **96** on generally opposite sides of the chamber **35**. In this version, the process monitoring system **25** may comprise a radiation source **150** to provide a radiation beam **148a** through one of the windows **130** to be incident on the substrate. Through the other window **130** the reflected radiation beam **148b** from a substrate **30** may be detected by radiation detector **160** for interferometric or ellipsometric analysis. Alternatively or additionally, a window **130** in the sidewall **96** may be shaped and sized to monitor a spectral emission from the plasma, for example to perform a plasma emission analysis. As shown in Figure 1c, one or more of the windows may comprise a recess **145** of the type discussed above. The window **130** and/or the recess **145** may be inclined relative to the sidewall **96** at an angle of from about 5 degrees to about 85 degrees, more preferably from about 60 degrees to about 70 degrees, depending on the dimensions of the chamber **35** and the desired incident angle of the radiation beam **148a**.

Instead of being integral with the wall, the window **130** may also comprise a separate structure positioned on the ceiling **55**, as for example shown in Figure 2a. In this embodiment, the window **130** comprises a plug **132** of radiation permeable material sized to fit a matching aperture **134** in the ceiling **55**. For example, the plug **132** may comprise a disc **133** with an outwardly extending post **136** whish is smaller than the depth of the aperture **134**. The disc **133** is sized to rest on a circular ledge **138** that extends out of the ceiling **55** and a seal **139** may be formed between the disc **133** and the circular ledge to contain the gaseous environment in the chamber **25**. The top of the post **136** and the

surrounding sidewalls of the aperture **134** define the recess **145** in the wall **38**, as shown in Figure 2b. This embodiment is advantageous because the plug **132** may be replaced when eroded, may be removable for cleaning, or may be changed for monitoring different processes.

In another embodiment, the wall **38** comprises a mask or masking portion **140** (used interchangeably herein) that is discrete and separate from the wall **38** as shown in Figures 3 and 4, or that is integral with the wall **38** as shown in Figures 5a,b and 6a-c. By mask or masking portion **140** it is meant a structure, which may be part of the wall **38**, part of the window itself, or a separate structure, that serves to reduce the formation of process residues on the window **130**. In the example of Figure 3, the window **130** comprises a plate **135** that is mounted over an aperture **134** in the ceiling **55** of the chamber **35**, and is made from a radiation permeable material as described herein. The overlying masking portion **140** has at least one recess **145** extending therethrough. The masking portion **140** covers the surface of the plate **135** that would otherwise be exposed in the chamber **35** so that radiation may pass through the recess **145** and the window **130** while reducing the deposition of process residue and byproducts on the window **130**. The masking portion **140** may be made of a material that is resistant to erosion by the process gas or plasma in the chamber **35**, such as a plasma resistant material, for example, one or more of Al_2O_3, SiO_2, AlN, BN, Si, SiC, Si_3N_4, TiO_2 and ZrO_2; or may be the same material as the window **130** or the wall **38**.

Such a masking portion **140** and recessed window **130** have been found to reduce the rate of formation of etchant residues during polysilicon etching to about 3 to about 10 Å/hr, which is about 100 times lower than the rate measured for unprotected windows of about 0.03 to 0.1 microns/hour. In addition, the masking portion **140** may also protect the window **130** from erosion by chemically reactive process gases to extend the lifetime of the underlying window **130**. The reduced deposition of process residue on the window **130** provides a higher signal to noise ratio of the process monitoring systems **25** and more accurate and reliable radiation readings even after processing of a large number of substrates **30** in the chamber **35**. If a plasma resistant window material is used, such as sapphire, the aspect ratio can be chosen so that little or no residue forms on the window **130**, allowing the window **130** to be used many times without cleaning. A more accurate process monitoring method allows the deposition or etching of thinner films on the

substrate **30**. In addition, the chamber utilization efficiency and substrate throughput may be increased because the process chamber **35** does not have to be frequently opened to clean the surface of the window **130**.

The window **130** may also comprise a radiation permeable plate **135** that is mounted at an angle relative to the plane of the substrate **30,** or relative to the angle of incidence of reflected radiation onto the plate **135**, as shown in Figure 4. The tilt angle of the window **130** reduces the reflection of radiation passing through the window **130** that originates from the radiation source or is reflected from the substrate **30**. A suitable tilt angle may be at least about 2 degrees, and preferably less than about 15 degrees. The plate **135** may be tilted at an angle by elevating a side or edge of the plate **135** relative to the opposing side/edge, for example, by providing a step **152** below the plate **135**. In one embodiment, the step **152** was sized from about 0.5 mm to about 5 mm.

The masking portion **140** of the wall **38** may also comprise a plurality of recesses **145**. For example, the array of recesses **145** shown in Figures 7a and 7b, comprise a cumulative opening area that is sufficiently large to allow a suitable intensity of radiation to pass through. The recesses **145** may also be spaced apart to allow a source radiation beam **148a** to be scanned across the surface of the substrate **30** or positioned over a particular feature such as a via, trench, or flat portion of the substrate **30**. For example, in a chamber **35** that is used to process 300 mm wafers, the wall **38** may comprise an array of recesses **145** that have a total cumulative opening area of from about 200 to about 2000 mm^2 (0.3 to about 3 in^2), and more preferably from about 400 about 600 mm^2 (0.6 to about 0.9 in^2). The actual size, number and arrangement of recesses **145** depends upon the chamber size and geometry, the substrate diameter, the process being performed, and the requirements of the process monitoring system **25**. In an embodiment useful for interferometric process monitoring systems **25**, the masking portion **140** may comprise, for example, an array of about 3 to about 800 recesses or from about 7 to about 200 recesses, and the recesses **145** may be spaced apart by about 0.25 to about 15 mm.

The array of recesses **145** may also be arranged in a showerhead configuration with each recess **145** being shaped, for example, as a cone with the walls of the recesses **145** abutting one another, as shown in Figure 6c. The array of recesses

145 may be disposed or oriented to view a wide area of the substrate **30** in interferometric or ellipsometric analysis, or one or more preselected regions of the plasma in plasma emission analysis. The array may also comprise different sized recesses **145**, for example, a first recess **145a** located above a central portion of the window **130** and having a diameter of, for example, 3.5 to 5 mm; and a plurality of second recesses **145b** located above a peripheral portion and having a diameter of, for example, 2 to 3 mm, as for example, shown in Figure 7b.

In yet another embodiment, the recesses **145** comprise hexagonal openings and they are closely spaced, for example, as illustrated in Figures 8a and 8b. In this embodiment, the recesses **145** are in a masking portion **140** shaped as a right cylinder and sized to cover substantially the entire exposed portion of a disc-shaped window **130**. In this version, the masking portion may comprise a separate structure made of aluminum oxide. In the embodiment shown, the masking portion **140** comprises a raised pedestal **153** having a surrounding annular lip **154**. The raised pedestal **153** may have a thickness of from about 0.5 mm to about 500 mm, a diameter of from about 50 mm to about 200 mm, and a rounded corner to reduce plasma erosion. The annular lip **154** may be sized to allow the masking portion to be easily attached to the chamber **35** and its thickness may be from about 0.5 mm to about 10 mm.

In another embodiment of the present invention, as for example, schematically illustrated in Figures 9a and 10a, the process chamber **35** comprises an electromagnetic field source **190** adapted to provide an electromagnetic field or energy about and near a portion of the wall **38**, for example, about the recess **145**, and optionally, about the window **130**. When a substrate **30** held on the support **45** is processed by the energized process gas, the electromagnetic field about the wall **38** reduces the deposition of process residues on the wall **38**, in the recess **145**, or on the window **130**.

For example, in the embodiment shown in Figure 9a, the electromagnetic field source **190** may comprise a magnetic field source **195** adapted to maintain a magnetic field near the portion of the wall **38**, about the recess **145**, or across the window **130**. The magnetic field source **195** comprises at least one magnet **200** or electromagnet (not shown) positioned adjacent or abutting to the wall **38**, recess **145**, or window **130** to provide magnetic energy thereabout. The magnetic field source **195** may provide a

magnetic field that is preferentially concentrated across the recess **145** or window **130** relative to other portions of the chamber **35**. For example, the magnetic energy (as represented by the magnetic field lines) may be confined to a space about the recess **145** or window **130**, and it may also penetrate only a small distance into the chamber **35.**

The magnetic energy may be applied to control entry of gas species into the recess **145** or access of the gas species to the window **130**. For example, the magnetic energy may have magnetic field components which are provided parallel to the plane of the wall **38** or the window **130** to confine or repel charged plasma ions and electrons of the plasma away therefrom and thereby reduce or prevent the deposition of process residues from these gas species on the wall **38** or window **130**. It is believed that a magnetic field having a component in the plane parallel to the wall **38** or window **130** may cause charged ions and electrons within this region to rotate in a circular motion about this region and thus prevent them from reaching the wall **38** or window **130**. The actual magnetic strength depends upon the window size, energy of the plasma ions, and other factors. However, a suitable magnetic field strength is from about 10 to about 10,000 Gauss or even from about 50 to about 2000 Gauss.

In the embodiment illustrated in Figure 9a, the magnetic field source **195** comprises a plurality of magnetic poles **205** disposed about a perimeter of the window **130** and having opposing magnetic polarities facing one another, such as facing north and south poles **205a,b**. In another embodiment, shown in Figure 9b, the magnetic field source **195** comprises a magnetic yoke **210**, typically a ferromagnetic material having magnetic poles **205a,b** which are oriented to maintain a magnetic field across an aperture **215**. The magnetic yoke **210** comprises a pair of radially extending poles **205a,b** that face one another with opposing magnetic polarity. Alternatively, as shown in Figure 9c, the magnetic field source **195** may comprise a plurality of magnets **200** having magnetic poles **205** facing one another across an aperture **215** sized to allow radiation to pass through the window **130** to operate the process monitoring system **25**. The aperture **215** may be circular, triangulated or rectangular; however, a circular opening generally provides good axial symmetry for the magnetic field source and smooth internal surfaces that are often less susceptible to erosion by the plasma.

In another embodiment, as illustrated in Figure 10a, the electromagnetic field source **190** comprises an electrical field source **220** that provides electrical energy about

the wall **38**, recess **145** or across the window **130** to maintain an electrical field thereabout. The electrical field may be adapted to reduce deposition of process residues on the wall **38**, in the recess **145,** or on the window **130**, for example, by repelling the charged residue forming gas species or by causing energized gas species to impinge upon and bombard the window **130** to etch away the process residues. The electric field source **220** may comprise an electrode **225** that is adjacent to, abutting, or behind the wall **38**, about the recess **145**, or near the window **130**, to couple electrical energy thereabout. The electrical field may be adapted to have electrical field components which are parallel or perpendicular to the plane of the wall **38** or window **130**. The electrode **225** may be sized sufficiently large to provide an electric field that covers the entire area of the wall **38** or only the window **130.** A voltage source **245** electrically biases the electrode **225** with a DC, AC or RF voltage. As shown in Figure 10a, the voltage source **245** may be an electrical tap **250** connecting a selected coil of the inductor antenna **100** to the electrode **225**. Thus, the antenna power supply **104** may be used to power both the electrode **225** and the inductor antenna **100**, or bias the electrode **225** with a voltage of from about 10 to about 10,000 volts, and more preferably from about 20 to about 4000 volts.

The electrode **225** may also comprise eddy current reducing slots **232** that are shaped and sized to reduce any eddy currents that may be induced in the electrode **225**. The eddy currents may occur due to the coupling of electrical energy to the electrode **225** from other process components, such as the inductor antenna **100**. The eddy current reducing slots **232** impede a flow path of eddy current in the electrode **225**. For example, in the embodiment shown in Figure 10b, the electrode **225** comprises a disc **235** having eddy current slots **232** comprising one or more radial cutouts **240** that impede circular eddy currents. In other embodiments, in Figures 10c and 10d, the eddy current slots **232** comprise a series of wedge-shaped cuts **242** or an array of circular holes **243** and slots **240** which are spaced apart from one another.

It should be noted the afore-described recess **145** or masking portion **140** may also be used in combination with either version of the electromagnetic field source apparatus **190**. For example, a masking portion **140** having the recess **145** may be aligned over an aperture **215** in a magnetic yoke **210** or over an aperture **230** in an electrode **225**, so that the recess **145** is aligned to the apertures **215** or **230**. For example, Figure 10e illustrates a wall **38** comprising a recess **145** which is sized and distributed to match the

apertures **230** in the electrode **145**. As another example, Figure 10f illustrates an embodiment in which the electrode **225** abuts a large recess **145** defined by a window **130** comprising a radiation permeable plug **132**.

Operation of an exemplary process chamber **35** according to the present invention having a wall **38**, a recessed window **130**, and a process monitoring system **25**, will now be described with reference to Figure 2. In this example, the process monitoring system **25** comprises an interferometric system that evaluates a property of a substrate reflected radiation beam **148b**, such as its intensity, to determine the endpoint of the etching process. The process monitoring system **25** comprises a radiation source **150** that may be outside or inside the chamber **35** to provide a source of radiation in the chamber **35**. The radiation source **150** may comprise, for example, an emission from a plasma generated inside the chamber **35** which is generally multi-spectral and provides radiation having multiple wavelengths across a spectrum. The radiation source **150** may also be positioned outside the chamber **35** so that an incident radiation beam **148a** from the source **150** may be passed through the window **130** and recess **145** and into the chamber **35**. The external radiation source **150** may provide radiation such as ultraviolet (UV), visible or infrared radiation; or may provide other types of radiation such as X-rays. In one embodiment, the radiation source **150** provides radiation having a predominant wavelength, such as a monochromatic radiation having primarily radiation at a single or a few wavelengths, for example, a He-Ne or Nd-YAG laser.

In another embodiment, the radiation source **150** provides polychromatic radiation which may be selectively filtered to provide substantially only a single wavelength. For example, suitable radiation sources **150** for providing polychromatic radiation include a plasma emission in the chamber, mercury discharge lamps that are capable of generating a polychromatic radiation spectrum having wavelengths in a range of from about 180 to about 600 nanometers; arc lamps such as Xenon, Hg-Xe and tungsten-halogen lamps; and radiation emitting diodes, such as LEDs. The polychromatic radiation source **150** may be filtered to provide an incident radiation beam **148a** having selected frequencies, particular plasma emission spectra wavelengths can be used, or color filters (not show) can be placed in front of a radiation detector **160** to filter out undesirable wavelengths prior to measuring the intensity of the reflected radiation beam **148b** entering the radiation detector **160**. Also, the incident radiation beam **148a** may comprise non-polarized radiation

because the polarization state of a polarized radiation may be altered by process residues formed on the process window **130.** However, a deposition free window **130** as described herein would allow the use of polarized light because little or no process residues would be formed on the window **130**.

The radiation source **150** may be also adapted to direct a radiation beam **148a**, such as a laser beam at nearly a right angle relative to the surface of the substrate **30**, i.e., at an angle of close to 90° to measure etching of features having a high aspect ratio, which may otherwise be blocked from a radiation beam directed at low or acute angle onto the substrate **30**. Typically, one or more convex focusing lenses **165** are used to focus a radiation beam **148a** from the radiation source **150** into a collimated beam that is directed onto the substrate surface and/or to focus reflected radiation **148b** back from the substrate **30** to the radiation detector **160**. Generally, the area of the incident beam spot is large (relative to the size of the features) to compensate for variations in surface topography of the substrate **30** for example in the etching of high aspect ratio features having small openings, such as vias or deep narrow trenches; however, it may also be small to focus the beam incident spot onto particular features of the substrate **30**.

Optionally, a positioner **170** may be used to move the incident radiation beam **148a** across the substrate surface to locate a suitable portion of the substrate being processed on which to "park" the beam spot to monitor processing of the substrate **30**. Typically, the radiation beam positioner **170** comprises one or more primary mirrors **175** that rotate at small angles to deflect the incident radiation beam **148a** from the radiation source **150** onto different positions of the substrate surface, and to receive the reflected radiation beam **148b** and focus it on the radiation detector **160**. In another embodiment, the positioner **170** scans the source radiation beam **148a** in a raster pattern across the substrate surface during processing. For example, the beam positioner **170** may comprise a scanning assembly consisting of a movable stage (not shown), upon which the radiation source **150**, focusing assembly, collecting lens, and detector **160** are mounted. The movable stage may be moved through set intervals by a drive mechanism, such as a stepper motor, to move the incident beam spot across the substrate surface.

The radiation detector **160** comprises an electronic component having a radiation sensitive surface which provides a signal in response to the intensity of the

reflected radiation **148b**. In interferometry, the reflected radiation **148b** undergoes constructive and/or destructive interference to provide an intensity that fluctuates as the thickness of the layer being processed or the depth of trench being etched on the substrate **30** increases or decreases, respectively, and the radiation detector **160** provides an electrical output signal in relation to the measured intensity of the reflected radiation **148b**. The detector **160** comprises a radiation sensor, such as a photovoltaic cell, photodiode, photomultiplier, or phototransistor, which provides an electrical output signal in response to a measured intensity of the reflected radiation **148**. The detector signal can comprise a change in the level of a current passing through an electrical component or a change in a voltage applied across an electrical component. The detector may comprise a photomultiplier (PMT), such as those commercially available from Hamamatsu, Japan.

A controller **155** receives the signal from the radiation detector **160**, evaluates the signal relative to calculated values, using an algorithm, or from stored values, and changes process conditions in the process chamber **35** in relation to the evaluated signal or according to programmed guidelines. For example, upon detection of a process endpoint, the controller **155** may change first process conditions to second process conditions to change a rate of etching of a layer on the substrate **30** before the entire layer is etched through, or to stop the etching process. The etch rate may be reduced by changing the composition of the process gas to reduce the content of the more chemically reactive etchant gases, the RF energy coupled to the process gas may be lowered, or the substrate temperature may be lowered. A typical controller **155** comprises a computer comprising one or more central processor units (CPUs) interconnected to a memory system with peripheral control components, such as for example, a PENTIUM microprocessor, commercially available from Intel Corporation, Santa Clara, California. The CPUs can also comprise ASIC (application specific integrated circuits) that operate a particular component of the process chamber **35**. The interface between an operator and the computer controller **155** can comprise a CRT monitor and a radiation pen (not shown), or other devices, such as a keyboard, mouse or pointing communication device. A computer program or computer instructions may be used to operate the controller.

To perform the process, a substrate **30** is transferred by a robot arm (not shown) from a load-lock transfer chamber (not shown) through a slit valve and into the process zone **40** of the process chamber **35**, and placed on the support **45** where it is held by an electrostatic chuck **50**. Optionally, a heat transfer gas is supplied below the

substrate **30** to control the temperature of the substrate **30**. Thereafter, the process conditions in the process chamber **35** are set to process the layer on the substrate **30** the process conditions comprising one or more of process gas composition and flow rates, power levels of a gas energizer **60**, gas pressure, and substrate temperature. The process can also be performed in multiple stages, for example, each stage having different process conditions. For example, in an etching process, an energized process gas capable of etching the substrate **30** is energized and maintained at process conditions suitable for etching the substrate **30** in the process chamber **35**. Suitable process gases for etching layers on the substrate **30**, include for example, HCl, BCl_3, HBr, Br_2, Cl_2, CCl_4, $SiCl_4$, SF_6, F_2, NF_3, HF, CF_3, CF_4, CH_3F, CHF_3, $C_2H_2F_2$, $C_2H_4F_6$, C_2F_6, C_3F_8, C_4F_8, C_2HF_5, C_4F_{10}, CF_2Cl_2, $CFCl_3$, O_2, N_2, He, and mixtures thereof. By energized process gas, it is meant that the process gas is activated or energized so that dissociated, non-dissociated, ionic and neutral species may be excited to higher energy states. Also, initially, a reflectance machine may be used to determine the initial thickness of the layer to be etched on the substrate **30**, such as a model UV1050 available from KLA-TENCOR, Santa Clara, California. The actual layer thickness may be used to estimate the overall operation time of the etching process and/or to calculate the thickness of the layer that should be etched to provide a predetermined thickness of layer that remains on the substrate **30** after the etching process.

EXAMPLES

The following examples demonstrate the principles of the present invention; however, the invention may be used in other applications as would be apparent to those skilled in the art, and the scope of the present invention should not be limited to the illustrative examples provided herein.

In these examples, generally, an etching process was performed in a process chamber **35** and an interferometric signal of radiation reflected from the substrate **30** and passing through the window **130** was measured during the process. Generally, the etching process, where performed, comprised a main polysilicon etching stage that used a gas composition of 50 sccm CF_4 and 40 sccm SF_6, a pressure of 2 to 3 mTorr, a source power of 750 watts and a bias power of 90 watts. After a process endpoint was detected by the process monitoring system **25**, the main etch stage was stopped and additional polysilicon was removed in a second etching stage using 60 sccm of SF_6 at a pressure of

about 10 mTorr, source power of 600 watts, and bias power of 1 watt. At periodic time intervals, the window **130** was removed, and the thickness of process residue deposited upon, and the erosion depth into, the window **130**, were measured by a stylus step-height measuring device such as a DekTak or an Alpha-step. Also, during the etching process, radiation having a wavelength of 254 nm was reflected off the substrate **130**, and the % transmission of ultraviolet radiation passing through the window **130** was measured using a radiation source **150** of known intensity and a radiation detector **160** capable of accurately measuring the intensity of the transmitted radiation.

Example 1: Effect of Process Residues

In Example 1 (conducted to determine a baseline for comparative purposes) a substrate **30** was etched as described above, and %transmission measurements were taken at the beginning of the etching process when the window **130** in the chamber was clean and free of residue and during etching as process residues were deposited on the window **130**. The window **130** was open to the chamber and without any overlying masking portion **140**. The "clean window" line (a) in Figure 11a shows the measured transmission spectrum of the reflected radiation passing through the clean window **130**, and the "dirty window" line (b) shows the loss in transmission that occurs when process residues deposited on the window **130** for 52 hours of chamber operation. The change in transmission spectrum demonstrates the high absorption of the process residues deposited on the window **130**. Figure 11b further shows the reduction of the endpoint signal over time that occurs during the etching process. The endpoint signal amplitude was reduced by a factor of five or more due to the increasing thickness of process residue deposited on the window **130**.

Example 2: Masking Portion over Window

In Example 2, a mask **140** having an array of apertures **145** was positioned over the window **130** during an etching process and the same measurements were made as in Example 1. The aluminum oxide masking portion **140** comprised a raised pedestal **153** surrounded by an annular lip **154** (as illustrated in Figures 8a and 8b and with the chamber orientation of Figure 3). The raised pedestal was about 19mm (0.75") thick and contained an array of 19 hexagonal recesses sized having an opening width of about 3.8

mm (0.15") and an aspect ratio of 5:1. The masking portion **140** was positioned about 0.038" from the window **130**.

After operating the etching chamber for 80 minutes, the window **130** was disassembled. The thickness of process residue accumulated at portions of the window **130** -- and the depth of erosion of the window **130** -- were both measured. The masking portion **140** and its recesses **145** were found to significantly reduce the formation of process residue on the window **130** because the thickness of process residue was found to be below measurable limits. The window **130** was not eroded during the etching process. In addition, the percent change in transmission of ultraviolet radiation through the window **130** was also found to be below detectable limits, i.e., less than 1%.

Examples 3 to 11

These examples were performed to determine the effect of different sized recesses **145** in a masking portion **140** covering window **130**. A masking portion **140** having a single circular recess **145** with a predetermined diameter and aspect ratio was, in turn, positioned over a window **130** in the chamber **35**. A polysilicon etch process was conducted in the chamber **35** for 80 minutes, and thereafter, the masking portion **140** was removed and the thickness of process residues formed on the window **130** was measured. Thereafter, the window **130** was replaced -- uncleaned -- and re-examined after an additional 18 hours of chamber operation. The experiment was repeated with new windows **130** and other masking portions **140** having recesses **145** with different diameters or aspect ratios, and for 25 hours of chamber operation. Table I summarizes the thickness of process residues formed upon, and the erosion depth into, the window **130** after 25 hours of chamber processing. Based on the experimentally measured residue thickness and erosion depth levels, the % transmission of radiation (254 nm) through a window **130** after 150 hours of etching was determined as shown.

TABLE I

No.	RECESS DEPTH (in)	ASPECT RATIO	THICKNESS OF PROCESS RESIDUES AT CENTER (Å)	EROSION AT EDGE OF WINDOW (Å)	PROJECTED TRANSMISSION OF 245 nm RADIATION AFTER 150 HRS OF CHAMBER OPERATION
3	1"	0.75	4000 to 5000	-3000 to -6000 Å at 5mm	High at edge; moderate in center
4	0.5"	1.5	0	-2500 Å	High
5	0.25"	3	550 to 650	-250 Å at 0.5mm	Moderate
6	0.2"	3.75	410 to 500	None	Moderate to High
7	0.15"	5	170 to 200	None	High
8	0.1"	7.5	70 to 100	None	High

In examples 9 to 11, the deposition of process residue was measured on windows **130** covered by different sized recesses **145**. These recesses **145** were arranged in arrays and the recesses having either (i) a depth of 0.75" and diameter of 0.3", (ii) a depth of 1.5" and diameter of 0.20", or (iii) a depth of 0.75" and diameter of 0.15". Essentially the same thickness of process residue and erosion depth were obtained in these specimens as for a window **130** having a single recess **145** with the same aspect ratio.

A summary of the process residue deposition and etching characteristics on windows **130** having different recess configurations, is shown in Figure 12. The results were unexpected and several effective process regimes were determined. For recesses **145** having large apertures, essentially a conventional unmasked window, the rate of deposition of process residues is high at about 600 angstroms/hour for the process example. For recesses having **145** small apertures (<0.3 inches) which correspond to large aspect ratios (>2), the deposition rate is much smaller and is reduced further as the diameter of the recess decreases. For recesses **145** having an intermediate sized apertures and aspect ratios of from about 1 to about 2, the physical deposition of process

residues is reduced but the plasma reaches the window **130**, producing net etching of the window **130**. Thus, for the described polysilicon etching process, one version the recesses **145** comprise an aspect ratio of from about 0.75:1 to about 7.5:1 and diameters of from 0.01 to about 1.5 inches.

The window erosion data was also used to predict that the window **130** may be used for at least 400 hours of chamber operation without replacement or manual cleaning, which is a significant improvement over the prior art, in which the window **130** had to be replaced far more often. In addition, a window **130** having an overlying masking portion **140** and recess **145** exhibited a rate of residue deposition or erosion that was much less than the erosion rate of a conventional unmasked window **130**.

Example 12

The data from the previous examples was used to design a masking portion **140** having a recess **145** with a depth of 1" and a diameter of 1.5". The masking portion **140** was mounted on a window **130** of a chamber **35** and a polysilicon etching process was run. After processing for 100 RF hours, measurements taken on the window **130** revealed an erosion depth of about 19 microns and a process residue thickness of about 13 microns, and the sidewalls of the recess **145** had a process residue thickness of about 18 microns. Radiation scattering tests performed on the window **130** indicated that the window life would exceed 400 RF plasma hours. In addition, the time at which process endpoint was detected was relatively stable and reliable, with no reduction in amplitude of the radiation signal, as demonstrated in Figure 13a, which shows the peak to valley amplitude of the reflected radiation signal (line 401) to 100 hours operation of the etching chamber **35**, along with a relatively constant photomultiplier (PMT) %gain (line 402). Figure 13b shows the transmission spectrum through the window **130** before (line 404) and after (line 403) 100 hours of etching operation showing little or no change in the spectrum of the radiation passing through the window **130** and hence little or no transmission losses after the etching process. The transmission at 254 nm actually increased slightly. The amplitude of the reflected radiation before (Figure 14 a) and after (Figure 14b) 100 hours of operation of the chamber **35** also shows little or no change in the height, position or shape of the measured waveform, when a masking portion **140** having a recess **145** was held over the window **130** during the etching process.

Examples 13 - 20

These examples demonstrate that a window **130** having a recess **145** in an overlying masking portion **140** may be used to reduce the deposition of process residue on the window **130** for a number of different processes. Figure 15 illustrates schematically the deposition rates of process residue on a window **130** for a number of different processes (along with the major constituents of the process gas) with and without a masking portion **140** on the window **130**. The bars with (M) beneath indicate the deposition rate obtained when a masking portion**140** overlies a window **130** and the other bars represent the deposition rate obtained without a masking portion. It is seen that for almost all the processes, the masking portion **140** significantly reduced the rate of residue deposition on the window **130**.

Additional tests were conducted to determine if there were any changes in the characteristics or properties of the etched substrate obtained by the etching process -- with and without a masking portion **140** in the chamber **35**. However, it was determined that the rate of etching of the substrate **30** and the other etching properties, such as the critical dimension loss and profile angle, remained the same, both with and without a masking portion **140** covering a window **130** in the chamber **35**. These experiments demonstrated that the masking portion **140** did not significantly affect the results of the etching processes.

The foregoing examples demonstrate that the present invention may be used to accurately and reliably monitor many different process conducted in a chamber **35**. The invention reduces the formation of process residues upon a window **130**, and may also reduce the erosion of the window **130**, in a chamber **35**. As a result an amplitude of interferometric radiation measured through the window **130** remained high even after etching of a large number of substrates **30**. The masking portion **140** and recess **145** also significantly reduced the attenuation of radiation transmitted through the window **130** for a large process run time, increased radiation signal detection levels, and reduced the need to stop processing to clean window **130**. Consequently, the chamber **35** may be advantageously used for an extended time without stopping to remove or clean the window **130**.

The present invention is described with reference to certain preferred embodiments thereof; however, other embodiments are possible. For example, the process monitoring system may be used for other applications, as would be apparent to one of ordinary skill, such as in sputtering chambers, ion implantation chambers, or deposition chambers. In addition, equivalent configurations of the window may be designed by others of ordinary skill based upon the teaching herein. Therefore, the spirit and scope of the appended claims should not be limited to the description of the preferred embodiments contained herein.